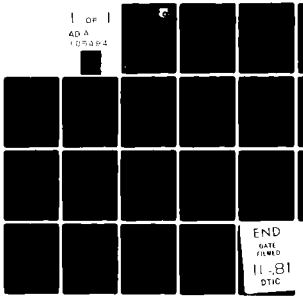
AD-A105 494 UNIVERSAL ENERGY SYSTEMS INC DAYTON OH F/G 20/4
INVESTIGATION OF PLASMA EXCITATION. VOLUME I. ELECTRON IMPACT S--ETC(U)
AUG 81 M L LAKE F33615-77-C-3113
UNCLASSIFIED AFWAL-TR-81-2082-VOL-1 NL



AD A105494

AFWAL-TR-81-2082
VOLUME I

INVESTIGATION OF PLASMA EXCITATION
VOLUME I. ELECTRON IMPACT STUDIES OF SELECTED GROUND STATE AND EXCITED STATE RARE GAS ATOMS

MAX L. LAKE
Universal Energy Systems, Inc.
3195 Plainfield Road
Dayton, OH 45432

AUGUST 1981

FINAL REPORT FOR PERIOD 7 JUNE 1977 to 20 SEPTEMBER 1980

Approved for Public Release; Distribution Unlimited

DTIC
OCT 15 1981
A

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433

DTIC FILE COPY

81 10 14

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Gary V. Duke

GARY V. DUKE, Capt, USAF
Project Engineer

Robert R. Barthelemy

ROBERT R. BARTHELEMY
Chief, Energy Conversion Branch
Aerospace Power Division

FOR THE COMMANDER

James D. Reams

JAMES D. REAMS
Chief, Aerospace Power Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/POOC-3 *W-PAFB, OH 45433 to help us maintain a current mailing list".*

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
AFWAL-TR-81-2082 - Vol-1	AD-A105494	

4. TITLE (and Subtitle)

INVESTIGATION OF PLASMA EXCITATION. Volume I. Electron Impact Studies of Selected Ground State and Excited State Rare Gas Atoms

5. TYPE OF REPORT & PERIOD COVERED: Final Report, 20 Jun 77 - 21 Sep 80

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Max L. Lake

8. CONTRACT OR GRANT NUMBER(s): F33615-77-C-3113

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Universal Energy Systems, Inc.
3195 Plainfield Road
Dayton, OH 45432

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
61102F
2301/S2/18

11. CONTROLLING OFFICE NAME AND ADDRESS
AF Wright Aeronautical Laboratories (AFWAL/POOC)
Wright-Patterson AFB, OH 45433

12. REPORT DATE: August 1981

13. NUMBER OF PAGES: 44

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cross Section
Metastable State Excitation
Electron Impact Excitation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experiments were undertaken to determine electron impact cross sections of atoms in metastable states. One or two electron guns were used to first produce atoms in metastable states, then further excite these atoms to other levels. Limits on certain cross sections of helium atoms were obtained, but the detection limits of the apparatus prevented exhaustive study. Excitation functions and cross sections of xenon were obtained in the wavelength range from 3000 A to 9000 A.

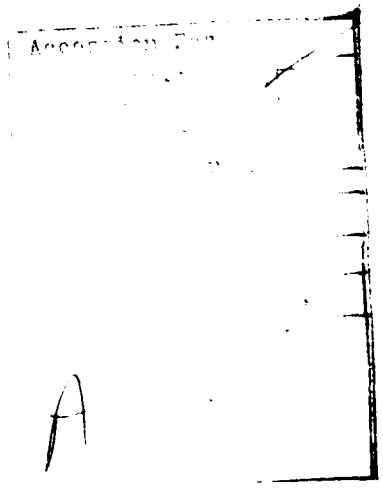
DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

SECTION		PAGE
I.	INTRODUCTION.	1
II.	EXPERIMENTAL PROCEDURE.	3
	1. General	3
	2. Single Step Excitation.	3
	3. Two Step Excitation	7
III.	RESULTS	9
	1. Excitation From the 2^1S State of Helium	9
	2. Excitation From the 2^3S State of Helium	12
	3. Triplet Excitation From the Helium Ground State . . .	14
	4. Excitation From the Ground State in Xenon	18
IV.	CONCLUSIONS	37
	REFERENCES.	38



LIST OF ILLUSTRATIONS

FIGURE		PAGE
1	Primary Elements of the Apparatus.	4
2	Energy Level Diagram for Helium Singlet System	10
3	Scheme for 2^3S Cross Section Measurement	13
4	Total Metastable Excitation Function in Helium	15
5	He 2^3S Excitation Function Interpreted from Borst and Holt and Krotov.	16
6	He 2^3S Excitation Function Data From This Experiment . .	17

LIST OF TABLES

TABLE		PAGE
1	Relative Intensities of Xenon I and Xenon II at 50 eV	20

SUMMARY

This work study was an effort to determine electron impact cross sections of helium atoms in the 2'S level to upper excited states. Excitation cross sections of ground state xenon was also studied. Due to the difficulty in obtaining a suitable target density of metastable atoms in the 2'S level, only an upper limit to the cross section under study was obtained.

Measurements of several optical transitions of xenon ground state atoms were made, and tables of values for these are presented.

SECTION I

INTRODUCTION

Since a significant fraction of the atoms or molecules in a plasma are in excited states, it is necessary to consider the influence of the excited state constituents on the characteristics of the plasma. While a large body of information exists for electron impact excitation and ionization of atoms and molecules in the ground state,[1] relatively few studies exist on the cross sections of atoms or molecules in excited states.[2-12] In a low density plasma, a majority of the excited states will decay in a time much shorter than the reciprocal of the average collision frequency. However, the metastable states in general have lifetime longer than the average time between collisions with either electrons or other atoms. The metastable states are much closer to the ionization threshold than the ground state, and atoms in metastable states may be ionized by a collision with an electron of much lower energy than that which would be required to ionize a ground state atom. Additionally, since the probability for a transition from one state to another state depends on the quantum configurations of both the initial and final states, the cross section for excitation of atoms in metastable states to other excited states is expected to be different from the cross sections from ground state atoms to those same excited states. In this study, experiment were undertaken to measure the cross sections of selected atoms in metastable states to other excited states.

Atoms were excited using either one or two electron beams. When using two beams, the first electron beam is set to have an energy sufficient only to excite the lowest metastable level of the atom.

Atoms in metastable states flow out of the first electron beam and into the second electron beam where they may be excited to higher levels. Decay radiation from the higher levels is the signal which is detected. Using a single electron beam, excitation from the metastable state of the atom is observed in the energy range from the threshold of excitation to a selected upper level. Since the interaction volume of the electron beam and gas contains atoms in metastable states as well as neutrals, excitation from metastable atoms to upper levels can occur, and can be detected by monitoring the decay radiation from the upper level.

As a part of this study, measurements of direct excitation from the ground state to optically allowed levels were made, also using a single electron beam.

SECTION II

EXPERIMENTAL PROCEDURE

1. General

Electron excitation experiments were performed in a vacuum chamber pumped by a turbomolecular pump to an ultimate pressure of 10^{-8} Torr. The chamber contained independently controlled electron guns which created parallel and non-intersecting electron beams. Atoms were excited in the volume defined by the intersection of an electron beam with an atomic beam with the equivalent pressure of 10^{-4} Torr. Experiments could also be performed with a static gas fill. The measured signal was the decay radiation from excited atoms. Primary elements of the system are illustrated in Figure 1. Decay radiation from the chamber is focused by a lens onto the entrance slit of Jarrell Ash one half-meter focal length monochromator to accomplish spectral line selection. An RCA 31034A photomultiplier tube was used to detect the radiation. Signal from the photomultiplier tube is fed into an SSR 1120 Discriminator/Preamplifier, and then to an SSR counter. The electron gun accelerating voltage was modulated with a 50% duty cycle, so that the SSR counter could be used to repetitively accumulate signal plus noise in one channel, and noise in a second channel, and display the difference after a selected integration time.

2. Single Step Excitation

For a selected excited state i, the net rate of excitation of the i^{th} state is a function of spontaneous emission out of the state, electron-atom and atom-atom collisions leading to population or depopulation of the i^{th} state, and cascade contributions by spontaneous

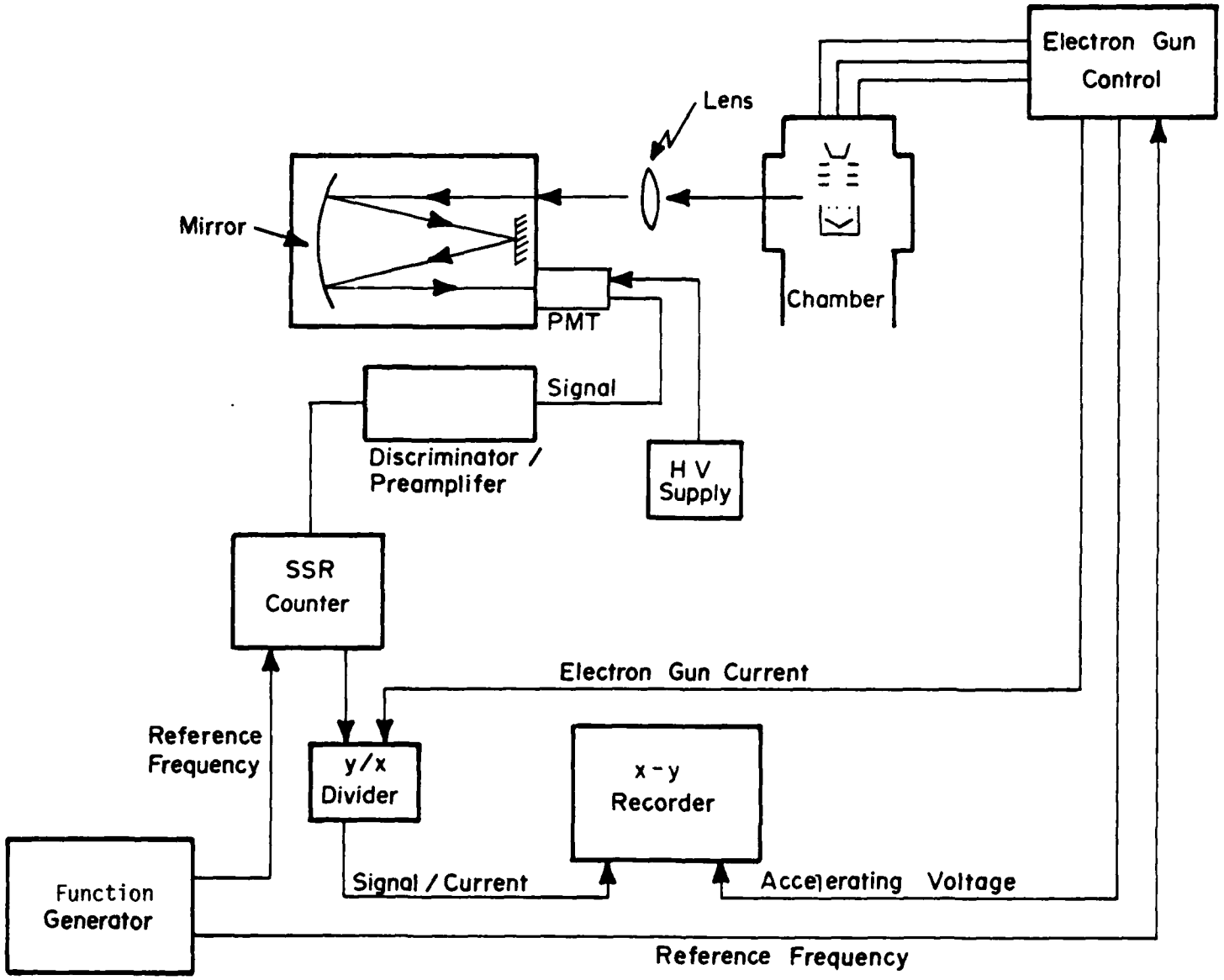


FIGURE 1 Primary Elements of the Apparatus

emission from higher states ending on the i^{th} states, as well as the cross section for direct excitation from the ground state. This may be expressed as follows, neglecting spatial gradients and electron quenching:

$$\begin{aligned} dN(i) = &\text{ Rate of direct excitation to the } i^{th} \text{ state} + \text{Rate of all cascades from higher states} \\ &- \text{Spontaneous emission from the } i^{th} \text{ state} + \text{Transfer of population into or out of the } i^{th} \text{ state due to atom-atom collisions} \end{aligned} \quad (1)$$

The third term of the right hand side of Eq. (1) may be determined by measuring the total photon flux from the i^{th} state to all lower states. The cascade contribution can similarly be determined by measuring the total photon flux for transitions ending on the i^{th} state. Population changes due to atom-atom collisions involving an electron excited atom are negligible when operating at a suitably low density of atoms. For steady conditions wherein $\frac{dN(i)}{dt}$ is zero, the rate of the atomic excitation to the i^{th} state due to electron collision may be determined by measuring the photon flux into and out of the state:

$$\text{Rate of excitation to the } i^{th} \text{ state by electron collisions} = \sum_{\substack{j \\ i>j}} F_{ij} - \sum_{\substack{k \\ k>i}} F_{ki} \quad (2)$$

where F_{ij} is the photon flux from $i \rightarrow j$ transitions and F_{ki} is the photon flux from $k \rightarrow i$ transitions.

The rate of excitation to the i^{th} state by electron collision is given by

$$\frac{N\Delta x\ Q(i)I}{e} \quad ,$$

where N is the number of atoms/cm^3, Δx is the path length of the electrons through the electron-atom interaction volume, I is the current through the interaction volume, e is the charge on an electron, and Q(i) is the inelastic collision cross section for ground state atom to the i^{th} state. Then

$$N\Delta x\ Q(i)\frac{I}{e} = \sum_{\substack{j \\ i>j}} F_{ij} - \sum_{\substack{k \\ k>i}} F_{ki} \tag{3}$$

It is seen that in order to determine the absolute level cross section Q(i), one must measure N, Δx, I, and the difference in the populating and depopulating optical transitions,

$$\sum_{\substack{j \\ i>j}} F_{ij} - \sum_{\substack{k \\ k>i}} F_{ki}$$

The probability of a transition from state i to j, i>j is designated the optical cross section of the spectral line and is written Q_{ij}. This may be expressed as

$$Q_{ij} = \frac{F_{ij}}{N\Delta x\ (I/e)} \tag{4}$$

These expressions may be used to analyze both excitation from the ground state to excited states, and from metastable states to excited states.

3. Two Step Excitation

As discussed previously, decay radiation on a selected optically allowed transition may be observed in a single electron beam below the energy threshold of excitation from the ground state, due to the excitation of atoms which are in metastable states. The ratio of photon flux above and below the ground state excitation threshold may be used to determine the apparent cross section for excitation of the metastable state to the selected optically allowed level. This is accomplished as follows.

For a selected optically allowed state k, the neutral density is related to the photon flux from the decay transition from the state by

$$N_o = \frac{F_{kj}}{Q_{kj}\Delta x(I_1/e)} \tag{5}$$

where N_o is the number of neutrals per cm , F_{kj} is the photon flux from the atomic line generated by the kj transition, Q_{kj} is the "line" or "optical" cross section, Δx is the path length of the electrons through the observed interaction volume, and I_1 is the electron current at the electron energy above the threshold for excitation from the ground state where the observation of the transition is made.

Assuming the excitation probability is much less than unity, the number density of atoms in the metastable state m is

$$N_m = \frac{N_o Q'_m \Delta x \; I_2/e}{\bar{v} A} \tag{6}$$

where Q'_m is the "apparent" cross section for excitation of the m level from the ground state (includes cascade excitation), $\bar{v}$ is the average velocity of the atoms in passing through the electron beam, and A is the area of the atomic beam. I_2 is the electron current at the electron energy below the ground state-to-excited state energy threshold and above the ground state-to-metastable state energy threshold where photon flux resulting from excitation from the metastable level is observed.

The apparent cross-section Q'_{mk} for excitation on the optically allowed transition from the metastable state m to another state k is

$$Q'_{mk} = \frac{F^*_{ki}}{B_{ki} N_m \Delta x \, I_2/e} \tag{7}$$

where F^*_{ki} is the photon flux observed on a transition k→i when the electron energy is between the excitation energy thresholds of states m and k. That is, the electron energy is insufficient for direct excitation of the k state from the atomic ground state. B_{ki} is the branching ratio for the k→i transition.

Combining equations 5, 6, and 7 yields:

$$Q'_{mk} = \frac{F^*_{ki} \, Q_{ki} \, I_1 \, \bar{v} \, Ae}{F_{ki} \, Q'_m \, (I_2)^2 \, \Delta x \, B_{ki}} \tag{8}$$

In this equation F^*_{ki}/F_{ki} is the ratio of the optical signal on the k→i transition when the exciting electron is insufficient for direct excitation of the k state, to that observed when the electron energy can directly excite the k state. To use this equation, the cross sections Q_{ki} and Q'_m and the branching ratio B_{ki} must be known.

SECTION III

RESULTS

1. Excitation From the 2^1S State of Helium

Work during the first phase of this study centered on obtaining measurements of two step excitation processes in helium and krypton. These experiments were follow-on efforts for work which was conducted in AFWAL/POOC-3 under a previous contract. (See Technical Report #AFAPL-TR-77-84)[13]

In helium, measurements of excitation from the 2^1S state were attempted. The 2^1S level has a radiative lifetime of 1 millisecond while the diffusion time from the volume of interaction of the electron beam is approximately 10^{-5} seconds. Therefore, excitation from the 2^1S metastable level to upper singlet levels should be possible. According to calculations by Flannery, et al.[12] a likely candidate for observations would be the He 6678Å ($3^1D \rightarrow 2^1P$) transition. (See Figure 2). The $2^1S \rightarrow 3^1D$ cross section has a predicted value of 1.1 x 10^{-15} cm^2 at 10 eV.

A drawback to this transition is the radiative background at the wavelength. The largest source of noise for this experiment is the black body emission from the cathodes and cathode heater filaments. While the noise counts from this source might be less than 50 per second, the noise count rate represents a limiting factor on the minimum signal which may be obtained. The following example illustrates this limitations.

The minimum observable signal is determined by the noise counts and the integration period:

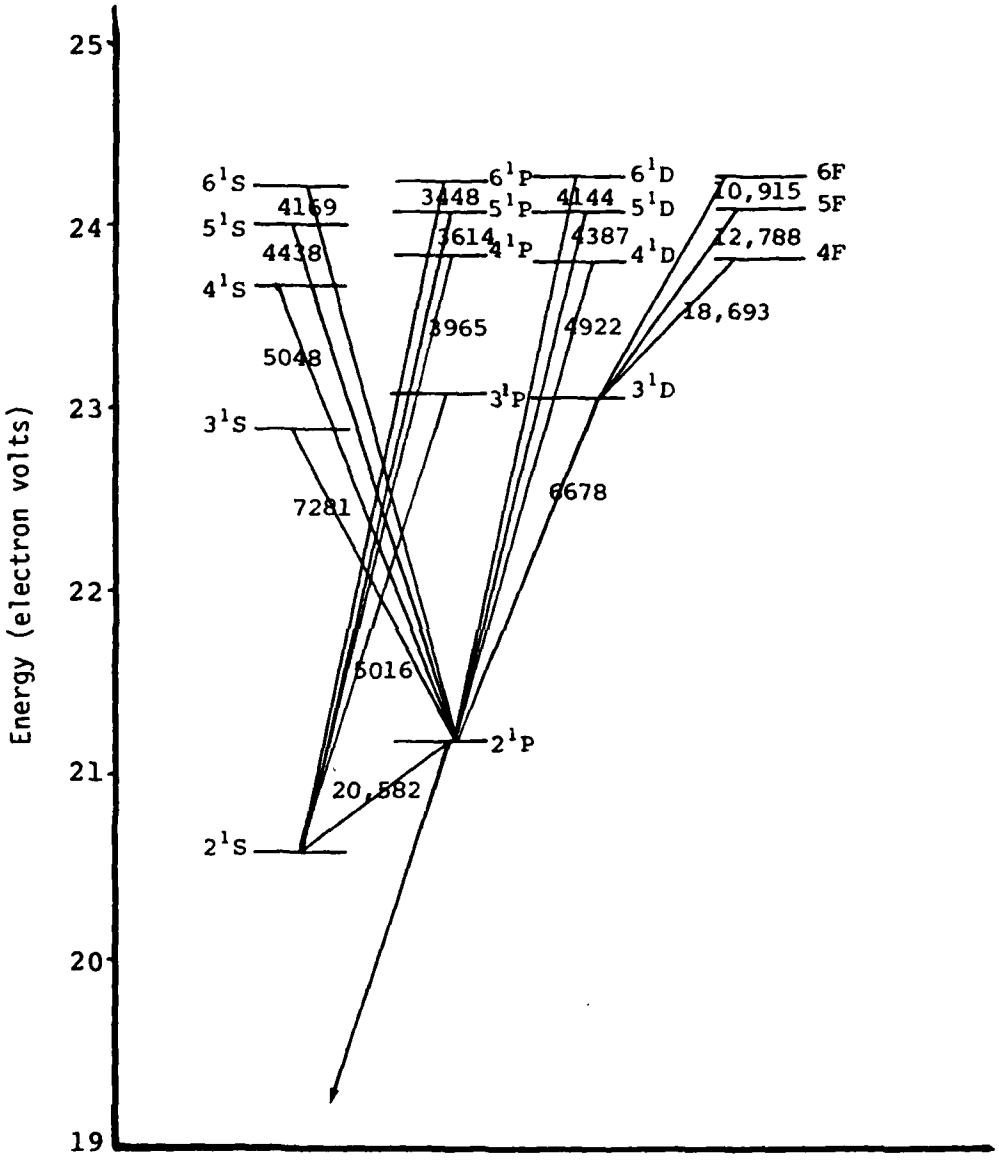


FIGURE 2 Energy Level Diagram for Helium Singlet System. The zero on the energy scale corresponds to the 1^1S ground state of helium.

$$\text{Signal} \sim (2N\tau)^{\frac{1}{2}} \tag{9}$$

where N = noise counts per second
τ = integration period

Noise sources for this experiment are the dark counts for the photomultiplier-tube PMT (<20 cps), and the black body emission from the cathode ($50<N<350$, for 350 nm $< \lambda <$ 800 nm) with 500 micrometer slits, and V_{PMT} = 1600V. A typical noise level might be 100 cps. Also, the maximum reasonable integration period is $\cong$1000 seconds, since the signal must be observed with a sufficient number of data points displayed over the width of the electron beam energy range to show all observable details of the excitation function, as the electron gun energy is swept.

Then

$$\begin{aligned} \text{Signal} &> (2 \times 10^2 \times 10^3)^{\frac{1}{2}} \\ &> 450 \text{ counts.} \end{aligned} \tag{10}$$

From equation 8 for measuring the cross section of a metastable atom, Q'_{mk}

$$F^*_{ki} = \frac{Q'_{mk} F_{ki} Q'_m (I_2)^2 \times B_{ki}}{Q_{ki} I_2 \bar{v} Ae} \tag{11}$$

By putting in approximate values for the above quantities, an estimate of the minimum direct signal strength can be determined. Using

$$\begin{aligned} Q_{ki} &= 3.5 \times 10^{-19} \text{ cm}^2 \\ Q'_m &= 5 \times 10^{-18} \text{ cm}^2 \\ Q'_{mk} &= 1.1 \times 10^{-15} \text{ cm}^2 \end{aligned}$$

$$F_{ki} = \frac{(5\times10^{2})(3.5\times10^{-19}\text{cm}^2)(2.5\times10^{-5}\text{coul/sec})(.2\text{cm})}{(1.6\times10^{-19}\text{coul/elec})(1.27\times10^{5}\text{cm/sec})}$$

$$\frac{}{(1.1\times10^{-15}\text{cm}^2)(5\times10^{-18}\text{cm}^2)[2\times10^{-5}\text{coul/sec})^2]}$$

$$= 8.08 \times 10^{6} \text{ counts or } 8 \times 10^{3} \text{ counts per second,}$$
assuming an integration time of 1000 seconds.

Using the appropriate values for the $3\rightarrow D^1 2\rightarrow P$ transition, it is ascertained that unless the cross section exceeds 10^{-16}, the measurement criterion defined in statement 10 cannot be achieved.

The data acquisition efforts for the subject transition produced a signal which did not achieve the measurement criterion although there was evidence of the two step signal of the appropriate energy threshold. The evidence was that the counts were no longer random around zero, but were favored towards the in-phase channel of the digital synchronous counter.

2. Triplet Excitation From the 2^3S State of Helium

In the foregoing, the first electron gun had been fixed in energy at 21 eV, while the second electron gun was swept in energy from 3 to 20 eV. In this way the excitation function of the helium 2^3S to $n^3\ell$ levels could be produced. Since 21 eV electrons can excite either the 2^1S or the 2^3S state from the ground state, both the singlet and the triplet system is probed by the second electron beam. The effects of excitation in the two systems is separable by identification of the optical transition from which emission is monitored. This is illustrated in Figure 3 for the helium triplet system.

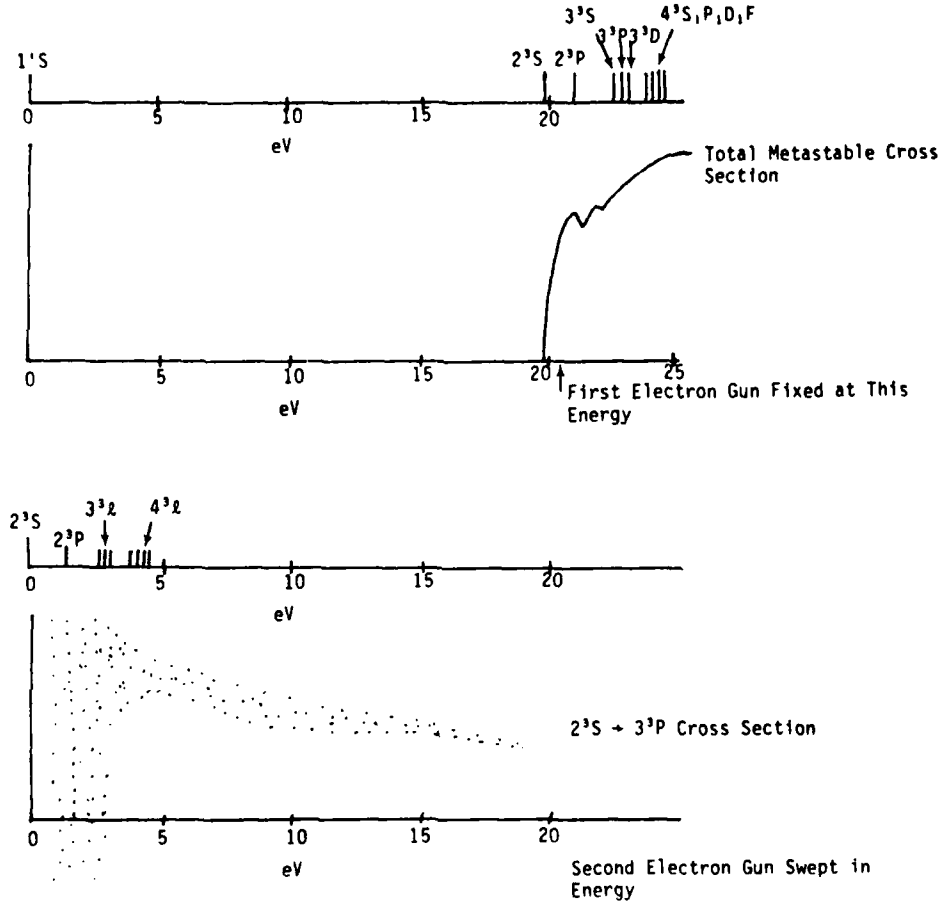


FIGURE 3 Scheme for 2^3S Cross Section Measurement

3. Triplet Excitation From the Helium Ground State.

If the second electron gun is fixed in energy at 15 eV, and the first electron gun is swept in energy, the decay radiation from the interaction volume of the second electron gun would be proportional to the excitation function of the helium $1^1S \rightarrow 2^3S$ cross section.

There are two good reasons for performing this experiment. First, the $1^1S \rightarrow 2^3S$ cross section as a function of energy has not been measured directly. The existing data for this cross section all include additional transitions for population at the 2^3S level, and some account must be made for these contributions. Figure 4 shows the total metastable result of Borst from Reference 14, and Figure 5 shows this author's interpretation of the $1^1S \rightarrow 2^3S$ cross section, made by normalizing the shape of the $1^1S \rightarrow 2^3S$ excitation function of Holt and Krotov[13] to the first peak of the total metastable[15] excitation function of Borst. The experiment described above is in principle capable of measuring directly the shape of the $1^1S \rightarrow 2^3S$ excitation function. The second good reason is that the experiment would confirm the validity of the data interpretation of previous work where the goal was to measure the 2^3S to $n^3\ell$ cross sections.

The experiment was performed under circumstances similar to the $2^3S \rightarrow n^3\ell$ measurements.[13] The second electron beam, fixed at 15 eV was 100% modulated. The first electron beam was swept in energy from 15 to 25 eV. Typical (best) data are shown in Figure 6. The first observation is that the signal to noise ratio is much less than optimum.

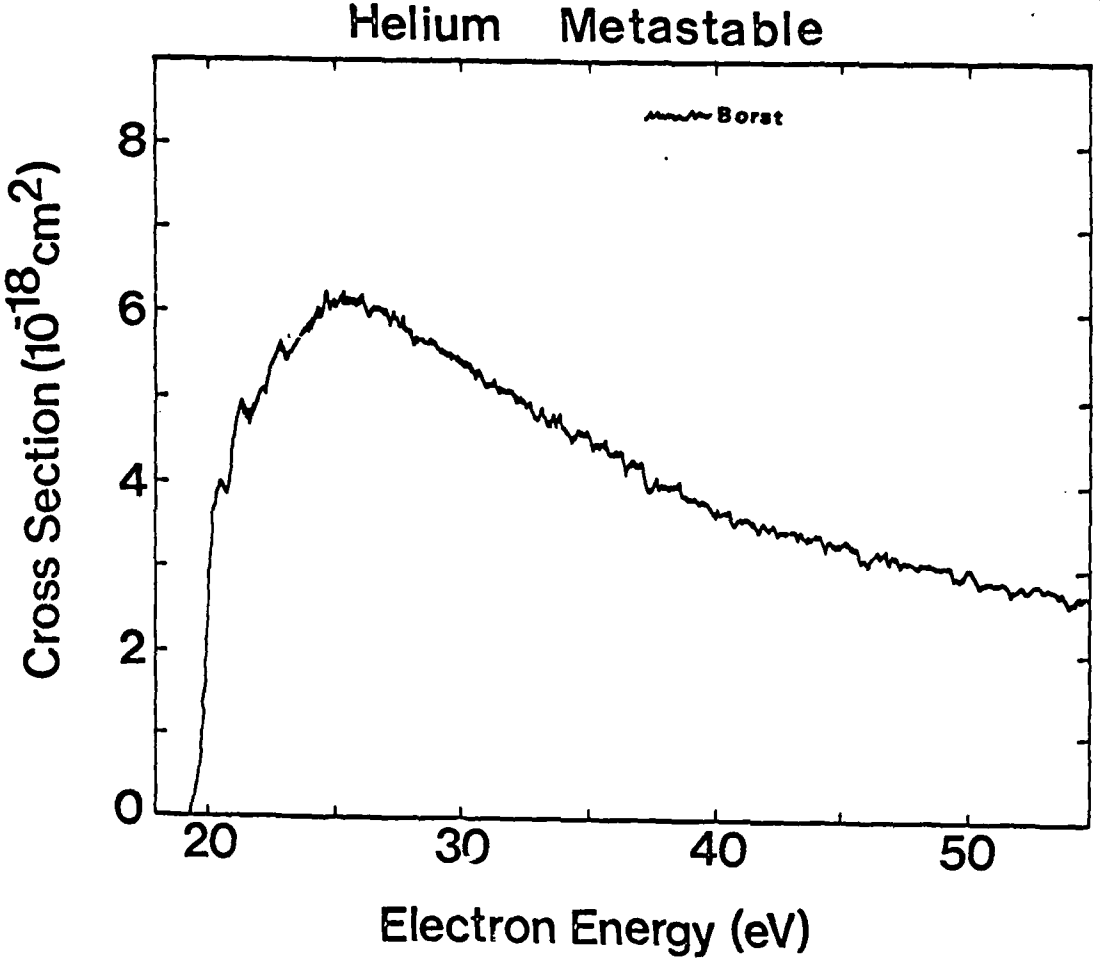


FIGURE 4 Total Metastable Excitation Function in Helium

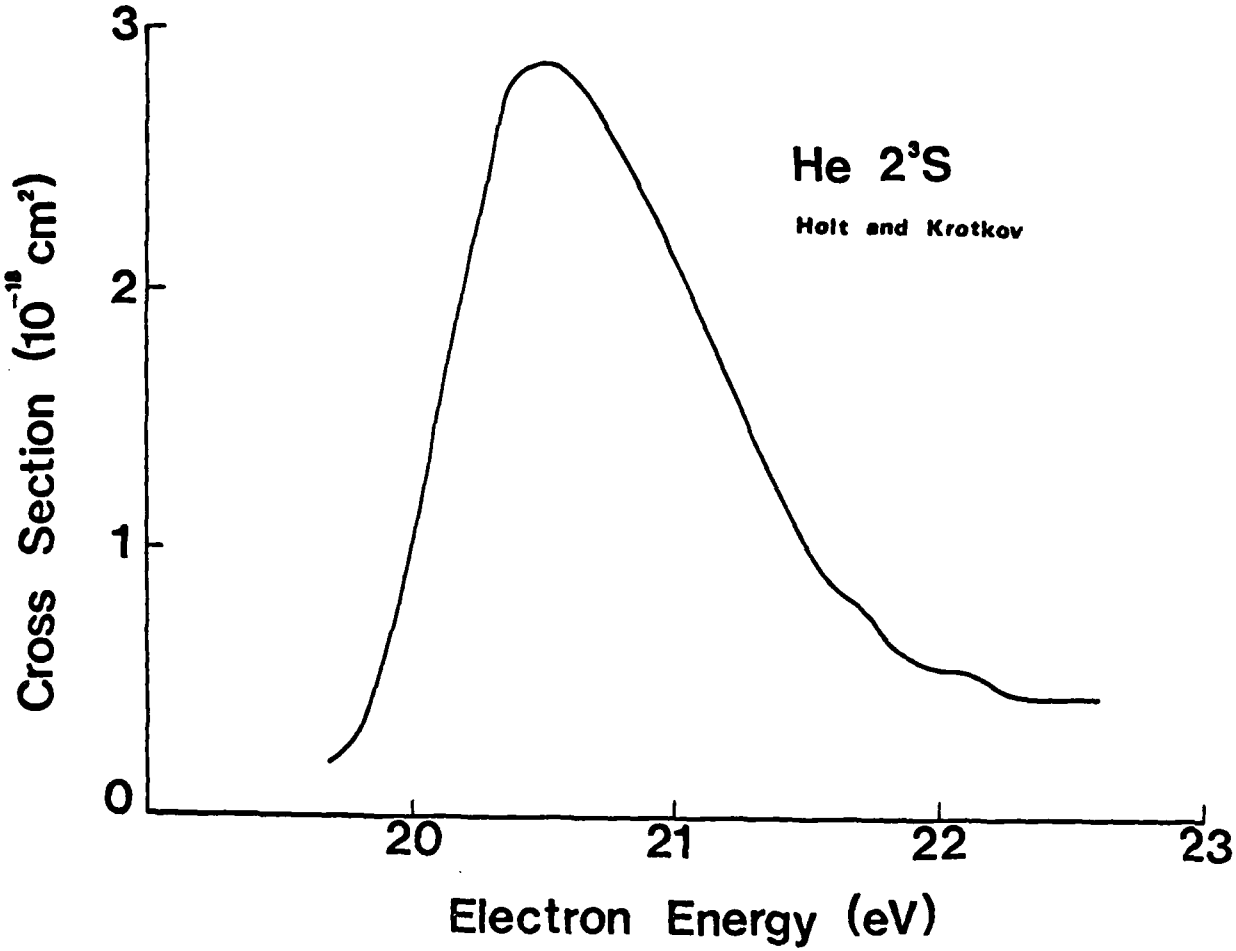


FIGURE 5 He 2^3S Excitation Function Interpeted from Borst and Holt and Krotov

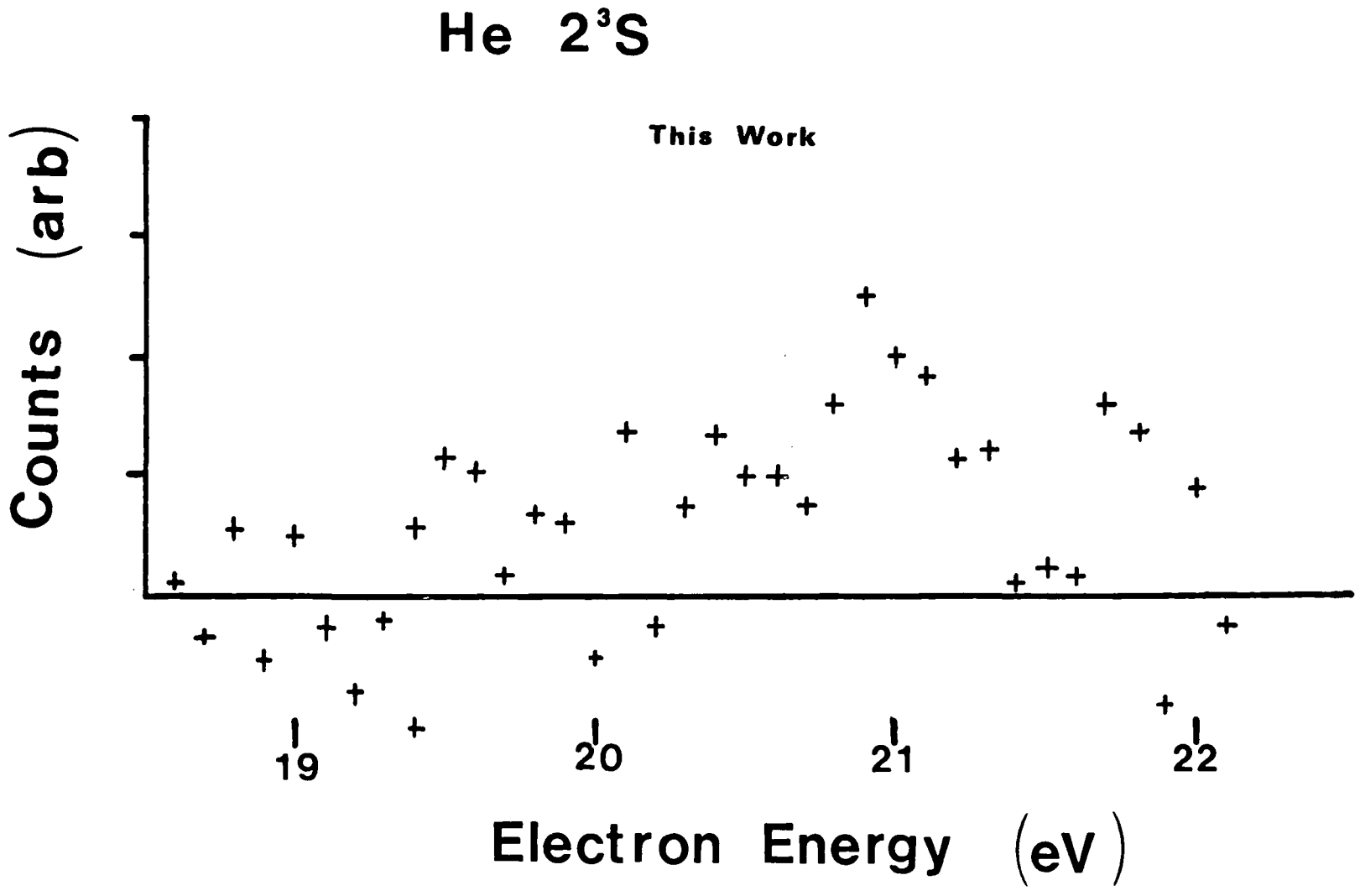


FIGURE 6 He 2^3S Excitation Function Data From This Experiment

However, further examination reveals that between 20 and 22 eV, the counts, each of which represents a one thousand second counting period, are not random about zero. Comparison with Figure 5 indicates that this energy regime contains the maximum of the helium $1^1S \rightarrow 2^3S$ cross section as inferred from Holt and Krotkov. Thus the non-randomness of the data in Figure 6 is an indication that two step excitation in the triplet system of helium. However, the scatter in the data precludes an estimate of the metastable density in the atomic beam. The data obtained are not of sufficient quality to improve on the knowledge of the excitation function for the $1^1S \rightarrow 2^3n\ell$ measurements.

4. Excitation From the Ground State in Xenon

In accord with equation 8, in order to use the ratio of photon flux above and below the ground state excitation threshold of a transition to determine the cross section from metastable states to the upper level of the transition, it is necessary to know the optical cross sections of the transition from the ground state. In the case of helium, this data had been compiled and published by other researchers. Optical and level cross sections of xenon have not received sufficient study to be known with an acceptable level of confidence. As a part of this study, measurements weremade of electron impact excitation functions in xenon. Excitation functions of 6p, 6p', 7p' , 8s, 5d', and 8d' levels were measured, and were published in a separate report.[16] During the course of that study, the need for high resolution spectra in xenon became apparent following difficulty in identifying the classification of several prominant lines and resolving others.

Presented in Table 1 are the spectral lines of xenon in the range of 3500Å to 9000Å, observable with the apparatus described in Section I, when the accelerating voltage is set at 50 volts, and the slit width of the monochromator is set to yield resolution of 4.8Å.

The measured wavelength of the spectral line is corrected with a calibration constant measured for the monochromator, and assignment to the nearest logical choice from the tables of spectral lines in Striganov and Sventitski.[17] Three spectral scans over a range of 500Å were normalized to the strongest transition in the range, and then averaged, to determine the intensity of the spectral lines. The spectral data is uncorrected for detector sensitivity.

TABLE I

RELATIVE INTENSITIES $\bar{I}$ OF XENON I AND XENON II AT 50 eV

λ		$\bar{I}$
3644.93	XeII	2.99 E2
3669.91		2.26 E2
3688.80		0.85 E2
3702.74		0.79 E2
3711.64	XeII	0.58 E2
3720.80	XeII	4.97 E2
3731.18	XeII	2.91 E2
3770.12	XeII	1.12 E2
3809.84	XeII	6.84 E2
3811.05		1.19 E3
3826.86		2.30 E2
3849.87	XeII	1.61 E2
3858.53	XeII	3.25 E2
3869.63	XeII	8.34 E2
3885.00	XeII	1.81 E2
3907.91	XeII	2.47 E2
3943.57	XeII	3.60 E2
3950.93		7.78 E2
3967.54		4.97 E2

TABLE I (continued)

λ		$\bar{I}$
3985.20		2.31 E2
3990.33	XeII	3.11 E2
4002.35	XeII	2.42 E2
4025.19	XeII	1.18 E3
4037.59	XeII	7.01 E2
4044.90	XeII	2.85 E2
4057.46	XeII	4.45 E2
4078.82		5.85 E3
4104.95	XeII	7.46 E2
4116.12		1.76 E3
4131.01	XeII	1.46 E2
4135.13		1.45 E2
4162.16	XeII	6.12 E2
4180.10	XeII	2.21 E3
4193.53		1.75 E3
4209.47	XeII	1.36 E3
4215.60	XeII	6.22 E3
4223.00	XeII	5.62 E2
4238.25	XeII	1.35 E3
4245.38	XeII	2.80 E3
4251.57	XeII	5.99 E2
4263.44	XeII	1.95 E2
4269.84	XeII	6.71 E2
4278.68	?	1.59 E2
4296.40	XeII	8.01 E2
4310.51	XeII	5.96 E2
4321.82	XeII	2.54 E2
4330.52	XeII	2.57 E3

TABLE I (Continued)

λ		$\bar{I}$
4337.02	XeII	3.78 E3
4360.32	XeII	1.14 E2
4369.20	XeII	5.79 E2
4385.77		4.55 E2
4395.77	XeII	2.65 E3
4406.88	XeII	3.08 E2
4414.84	XeII	2.15 E3
4440.95	XeII	1.52 E2
4448.13	XeII	1.71 E3
4461.19	XeII	2.40 E3
4470.90	XeII	5.01 E2

TABLE I (continued)

λ		$\bar{I}$
4480.86	XeII	5.89 E2
4500.98		6.45 E2
4507.11	XeII	4.05 E2
4524.68		3.05 E3
4532.49	XeII	1.49 E3
4540.89	XeII	7.44 E2
4550.79	XeII	2.97 E2
4582.75		2.74 E3
4592.05	XeII	1.28 E3
4603.03	XeII	1.82 E4
4615.50	XeII	2.63 E3
4624.28		6.55 E3
4633.30	XeII	1.61 E2
4651.94	XeII	1.37 E3
4671.23		7.04 E3
4697.02		2.14 E3
4708.21		2.34 E2
4715.18	XeII	7.69 E2
4721.00	XeII	3.17 E2
4734.15		1.70 E3
4748.31	?	2.76 E2
4769.05	XeII	1.04 E3
4775.76	XeII	4.33 E2
4779.18	XeII	3.99 E2
4787.77	XeII	6.58 E2
4792.62		5.93 E2
4799.15	XeII	2.18 E2

TABLE I (continued)

λ		$\bar{I}$
4807.02		4.77 E3
4818.02	XeII	2.12 E3
4823.41	XeII	9.27 E2
4829.71		2.15 E3
4844.33	XeII	1.08 E4
4853.77	XeII	5.56 E2
4862.54	XeII	1.98 E4
4876.50	XeII	5.61 E3
4884.15	XeII	4.22 E3
4887.30	XeII	4.43 E3
4905.20	XeII	1.97 E2
4921.48	XeII	7.00 E3
4933.44	?	2.09 E2
4954.30	?	0.93 E2
4972.71	XeII	7.96 E3

TABLE I (continued)

λ		$\bar{I}$
4988.77	XeII	1.23 E3
5012.83	XeII	1.03 E3
5023.88		2.92 E2
5028.28		3.18 E2
5044.92	XeII	5.32 E3
5052.54	XeII	4.65 E2
5069.82	XeII	1.77 E2
5080.62	XeII	1.13 E3
5092.02	XeII	1.38 E3
5108.75	XeII	3.07 E2
5122.42	XeII	6.41 E2
5125.70	XeII	7.23 E2
5149.55	?	1.10 E2
5162.71		2.55 E2
5178.82	XeII	6.59 E2
5184.48	XeII	9.43 E2
5191.37	XeII	2.65 E3
5201.42	XeII	2.60 E2
5226.62	XeII	1.80 E2
5247.75	XeII	2.93 E2
5261.95	XeII	5.63 E3
5268.31	XeII	6.12 E2
5292.22	XeII	9.79 E3
5313.87	XeII	1.87 E3
5327.90	XeII	1.99 E2
5339.38	XeII	4.99 E3

TABLE 1 (continued)

λ		$\bar{I}$
5363.27	XeII	7.30 E2
5368.07	XeII	8.92 E2
5372.39	XeII	3.73 E3
5392.80		1.00 E3
5400.45		3.60 E2
5419.15	XeII	1.04 E4
5438.96	XeII	2.85 E3
5450.45	XeII	5.99 E2
5460.39	XeII	6.53 E2
5472.61	XeII	9.99 E2

TABLE I (continued)

λ		$\bar{I}$
5488.56		9.10 E2
5496.07	XeII	2.47 E2
5515.18	?	3.09 E2
5525.29	XeII	2.78 E2
5531.07	XeII	1.40 E3
5552.39	?	8.11 E2
5566.62		1.50 E3
5572.19	XeII	6.13 E2
5581.78		7.98 E2
5594.37		3.83 E2
5618.88		1.12 E3
5633.24	XeII	3.99 E2
5646.19		1.80 E2
5652.84		2.68 E2
5659.39	XeII	1.39 E3
5667.56	XeII	1.79 E3
5688.37		3.20 E2
5695.75		1.39 E3
5709.80		4.28 E2
5716.20		1.59 E3
5726.91	XeII	1.55 E3
5733.48		2.41 E2
5740.17		1.40 E3
5751.03	XeII	1.38 E3
5758.65	XeII	9.75 E2
5776.39	XeII	1.18 E3
5800.91	?	2.00 E2
5814.51		4.82 E2

TABLE I (Continued)

λ		$\bar{I}$
5823.89		1.88 E3
5830.63		3.90 E2
5835.50	XeII	3.28 E2
5843.43		2.89 E2
5856.51		1.55 E3
5875.02		9.50 E2
5893.29	XeII	3.65 E3
5905.13	XeII	9.05 E2
5909.67	XeII	9.85 E2
5922.55		4.59 E2
5931.24		9.13 E2
5934.17		1.07 E3
5945.53	XeII	7.41 E2
5958.03	XeII	3.43 E2
5976.46	XeII	2.12 E3

TABLE I (continued)

λ		$\bar{I}$
5974.15		1.33 E3
5989.18		6.16 E2
5998.12		3.01 E3
6009.78		4.35 E2
6026.76		3.92 E2
6031.36		3.64 E2
6034.92		7.07 E2
6036.20		1.66 E3
6043.38		5.08 E3
6048.00		6.77 E2
6051.15	XeII	2.23 E3
6070.94		3.76 E2
6097.59	XeII	6.93 E2
6101.43	XeII	2.02 E3
6103.88		5.77 E2
6114.86		3.40 E3
6130.56		1.71 E3
6144.97		1.05 E2
6152.07		1.42.E2
6163.66		9.91 E2
6178.30		1.23 E3
6179.67		1.40 E3
6182.42		3.47 E3
6189.20		5.53 E2
6198.26		1.16 E3
6206.30		1.03 E3
6224.17		5.18 E2
6242.09		3.34 E2
6261.21		3.80 E2
6265.30		9.32 E2

TABLE I (continued)

λ		$\bar{I}$
6270.82	XeII	1.98 E3
6277.54	XeII	3.97 E3
6286.01		1.30 E3
6292.65		6.25 E2
6298.31	XeII	3.75 E2
6318.06		1.87 E3
6333.97		7.58 E2
6337.58		5.05 E2
6343.96	XeII	1.01 E3
6356.35	XeII	9.77 E3
6397.99	XeII	3.38 E2
6412.38		3.48 E2
6418.98		2.12 E3
6430.16		2.37 E2
6451.79		1.67 E3
6461.50		3.33 E2
6469.71		8.47 E2
6472.84		7.98 E2

TABLE I (continued)

λ		$\bar{I}$
6487.77		1.07 E3
6498.72		1.22 E3
6504.18		4.35 E2
6512.83	XeII	1.66 E3
6521.51		5.64 E2
6533.16		2.25 E3
6543.36		6.53 E2
6554.19		1.86 E2
6559.97		1.49 E3
6583.27		1.95 E2
6595.56		6.13 E3
6604.54		5.53 E2
6607.41		1.40 E3
6620.02	XeII	3.42 E2
6632.46		1.49 E3
6657.92		9.24 E2
6668.97		2.42 E3
6681.04		2.01 E3
6694.32	XeII	4.99 E2
6702.25	XeII	6.85 E2
6728.01		1.36 E3
6752.95		3.78 E2
6767.12		9.89 E2
6771.57		4.84 E3
6790.37	XeII	5.08 E2
6805.94	XeII	1.42 E3
6818.38		7.35 E3
6827.32		6.58 E2

TABLE I (continued)

λ	$\bar{I}$
6841.5	4.38 E2
6848.82	2.27 E3
6866.83	1.69 E3
6872.11	3.35 E3
6882.16	1.47 E3
6899.05	2.17 E2
6910.82	1.32 E3
6925.53	1.95 E3
6935.62	3.08 E3

TABLE I (continued)

λ		$\bar{I}$
6990.88	XeII	2.55 E3
7019.8		5.35 E2
7035.5		5.56 E2
7047.4		1.29 E3
7082.15	XeII	2.89 E2
7119.6		4.42 E3
7136.6		3.06 E2
7147.5	XeII	9.81 E2
7164.8		1.30 E3
7200.8		9.05 E2
7209.1		3.89 E2
7215.97	XeII	5.19 E2
7244.9		5.31 E2
7257.9		2.33 E3
7266.5		9.85 E2
7284.3		3.45 E3
7301.8		9.19 E2
7307.4		7.11 E2
7316.9		1.34 E3
7319.8		9.98 E2
7339.3		7.60 E3
7355.6		3.92 E2
7386.0		1.59 E3
7393.8		1.63 E3
7400.4		6.32 E2
7424.1		1.31 E3
7441.9		5.15 E2
7451.0		6.05 E2
7474.0	?	2.04 E3

TABLE I (continued)

λ		$\bar{I}$
7492.23		1.90 E3
7501.13		6.77 E2
7548.45	XeII	3.67 E2
7584.68		1.55 E3
7600.77		4.15 E2
7608.46		3.64 E2
7618.57	XeII	2.90 E2
7642.03		4.52 E3
7664.56		1.42 E3
7666.61		2.99 E2
7740.31		1.21 E3
7783.66		6.31 E2
7787.04	XeII	6.44 E2
7802.65		3.94 E3
7832.98		2.86 E2
7841.23		4.23 E2
7887.40		1.59 E4
7954.22		3.72 E2
7967.34		5.06 E3
8057.26		2.1 E2
8061.34		2.46 E2
8080.31		4.23 E2
8115.84	XeII	8.35 E2
8120.16	XeII	1.05 E2
8171.02		2.74 E2
8206.34		7.1 E2
8231.63		1.29 E3
8266.52		2.48 E3
8280.12		3.57 E3
8324.58		1.96 E2

TABLE I (continued)

λ	$\bar{I}$
8346.82	9.87 E2
8349.05	4.56 E2
8392.37	6.29 E2
8409.19	1.64 E3
8482.64	5.65 E3

TABLE I (continued)

λ		$\bar{I}$
8500.96		3.70 E2
8522.55		4.14 E2
8530.10		7.21 E2
8553.65		2.64 E2
8576.01		1.67 E3
8624.24		4.01 E2
8648.54		2.25 E3
8692.20		6.32 E2
8696.86		4.60 E2
8709.64		2.48 E2
8739.39		7.96 E2
8758.20		2.55 E2
8785.88	XeII	1.69 E2
8804.61	XeII	1.64 E2
8819.41		1.40 E4
8862.32		2.67 E2
8952.25		4.89 E2

SECTION IV

CONCLUSIONS

Results from the experiment to measure cross sections from the helium 2'S level were less than definitive, and dictated that a more favorable approach be taken to that class of cross section measurements. To provide supplementary data for metastable state excitation cross section measurements in xenon, excitation cross section measurements for ground state xenon were made, and a portion of these data are presented here. These spectral data will allow a more comprehensive analysis of ground state xenon cross sections, by enabling cascade analysis and by providing for identification of potential spectral overlap for excitation function measurements.

REFERENCES

1. Kieffer, L.J. "Compiliation of Low Energy Electron Cross Section Data", JILA Information Center Report #7, University of Colorado, Boulder, Colorado, (1969).

2. Latyscheff, G.D. and Leipunsky, A.I., Z. Phys., 65, 111 (1930).

3. Phelps, A.V. and Molnar, J.P., Phys. Rev., 89, 1202 (1953).

4. Neynaber, R.H., Trujillo, S.M., Marino, L.L., and Rothe E.W., Atomic Collision Processes, edited by M.R.R. McDowell, North Holland, Amsterdam, 1089 (1964).

5. Mityureva, A.A. and Penkin, N.P., "Excitation of Neon and Helium Lines in Collision between Electrons and Metastable Atoms", Opt. Spectry., 38, No. 2, 229 (1975).

6. Fite, W.L. and Brackman, R.T., "Proceedings 6th Int. Conf. Ionization Phenomena in Gases", 21 (1963).

7. Vriens, L., Bonson, T.F.M. and Smit, J.A., Physica, 40, 229 (1968).

8. Koller, H.H., Ph.D. Thesis, University of Zurich.

9. Long, D.R. and Geballe, R., "Electron-Impact Ionization of He(2s ^{3}S)", Phys. Rev. A, 1, 260 (1970).

10. Shearer-Izumi, W. and Botter, R., "Electron-Impact Ionization of Long-Lived Excited Helium Atoms", J. Phys. B: Atom. Molec. Phys., 7, No. 4, L125 (1974).

11. Dixon A.J., Harrison, M.F.A. and Smith A.C.H., "A Measurement of the Electron Impact Ionization Cross Section of Helium Atoms in Metastable States", J. Phys. B: Atom. Molec. Phys., 9, No. 15, 2617 (1976).

12. Ton-That, D., Manson, S.T. and Flannery M.R., "Cross Sections for Excitation and Ionization in e-He($2^{1,3}$S) Collision", J. Phys. B: Atom. Molec. Phys., 10, No. 4, 621 (1977).

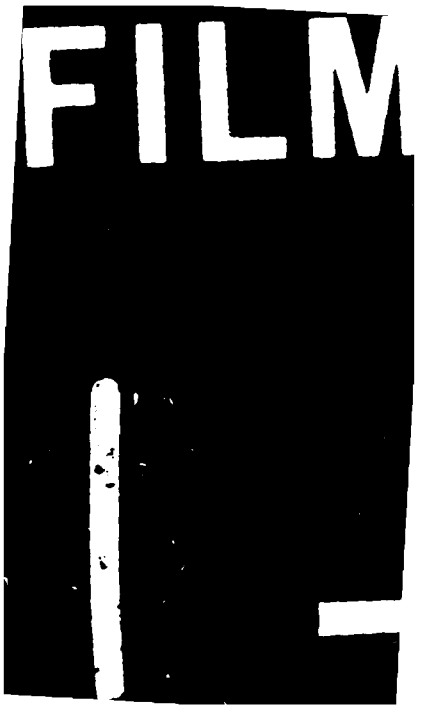
13. Lake, M.L., "Experimental Measurements of Cumulative Excitation and Ionization in Atomic and Molecular Gases", Technical Report AFAPL-TR-77-84 (1977).

14. Holt, H.K. and Krotkov, R., Phys. Rev., 144, 82, (1966).

15. Borst, W.L., Phys. Rev. A, 5 648 (1972).

16. Steven, M.D. "Measurements on Electron Impact Excitation Functions of Xenon Transitions", AFIT/GEP/PH/70D-11 (1979).

17. Striganov, A.R. and N.S. Sventitski, Tables of Spectral Lines of Neutral and Ionized Atoms, New York IFI/Plenum (1968).


FILM